Height distribution between cloud and aerosol layers from the GLAS spaceborne lidar in the Indian Ocean region

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[1] The Geoscience Laser Altimeter System (GLAS), a nadir pointing lidar on the Ice Cloud and land Elevation Satellite (ICESat) launched in 2003, now provides important new global measurements of the relationship between the height distribution of cloud and aerosol layers. GLAS data have the capability to detect, locate, and distinguish between cloud and aerosol layers in the atmosphere up to 40 km altitude. The data product algorithm tests the product of the maximum attenuated backscatter coefficient $b'(r)$ and the vertical gradient of $b'(r)$ within a layer against a predetermined threshold. An initial case result for the critical Indian Ocean region is presented. From the results the relative height distribution between collocated aerosol and cloud shows extensive regions where cloud formation is well within dense aerosol scattering layers at the surface. **Citation:** Hart, W. D., J. D. Spinhirne, S. P. Palm, and D. L. Hlavka (2005), Height distribution between cloud and aerosol layers from the GLAS spaceborne lidar in the Indian Ocean region, *Geophys. Res. Lett.*, *32*, L22S06, doi:10.1029/2005GL023671.

1. Introduction

[2] Both cloud and aerosols have important direct effects on the radiation balance of the earth. They influence the incoming solar energy by changing the albedo of the earth-atmosphere system and if absorbing they provide an increase in atmospheric radiative heating rates through the vertical range of their distribution. In addition, cloud and aerosol particles can interact with each other to produce significant secondary influences. For instance, *Twomey* [1974] describes how certain types of aerosols can increase low-cloud droplet concentrations, which would reduce incoming energy by increasing albedo without reducing the compensatory thermally emitted energy as much, and hence would be a cooling influence. More recent modeling studies [*Ackerman et al.*, 2003] support this theory while some satellite observations [*Platnick et al.*, 2000] seem to counter it. Opposed to the enhancement of low cloud cover by aerosol layers, there is evidence [*Ackerman et al.*, 2000] that heating by aerosol particles such as soot can reduce low cloud cover by absorbing incoming solar radiation. This is done both by evaporating cloud particles and stabilizing the boundary layer by preferred heating of its top. The interaction between aerosol and clouds are now also thought to be a major influence on precipitation [*Rosenfeld*, 2000].

[3] These examples of the opposing influences that the presence of aerosol has on the distribution and characteristics of cloud cover serve to illustrate the complexity of the atmospheric cloud-aerosol system. In order to quantify the effects that they impose on the earth's radiation balance, it is necessary that the global distribution of clouds and aerosol layers, especially with regard to their coincident occurrences, be well known. The height distribution of aerosol radiative forcing needs to be known separately and with correct clearing of cloud scattering [*Coakley et al.*, 2002]. In addition, the height distribution is an issue for the remote sensing of clouds. If there is significant aerosol scattering and absorption above cloud or elevated within clouds, passive multi-spectral techniques may be in error [*Sekiguchi et al.*, 2003]. Satellite observations provide a potential opportunity to find these distributions globally if the signals from the aerosols and clouds can be separated and vertically located. Spaceborne lidar offers a means to derive these kinds of products from backscatter measurements.

[4] The Geoscience Laser Altimeter System (GLAS) is a laser remote sensing instrument launched into orbit aboard ICESat in January, 2003. GLAS is a dual-purpose laser instrument, serving as both a precision surface elevation altimeter and atmospheric lidar [*Spinhirne et al.*, 2005]. Since February of 2003, GLAS has operated during discrete periods of approximately 33 days duration. When operating, it provides continuous and nearly pole-to-pole atmospheric lidar observations of clouds and aerosols through altitudes of 0–40km. A complete description of cloud and aerosol observations and analysis resolutions is given by *Palm et al.* [2002]. GLAS is sensitive to very optically rarefied particulate layers, down to backscatter cross section below 10^{-7} $(\text{m-sr})^{-1}$and is capable of detecting multiple layers to the limit of signal (optical depth < about 4.0).

[5] In this study, we introduce and present a brief summary of the GLAS cloud/aerosol algorithm. We show and discuss its strengths and weaknesses. Building on that, we present a case study in the heavily polluted Indian Ocean Region for the distribution of aerosol and clouds. We show GLAS's unique capability as a tool to accurately and comprehensively detect cloud and aerosols in the atmosphere and define their relative distribution.

2. Cloud/Aerosol Discrimination Technique

[6] A lidar signal is proportional to the attenuated backscatter coefficient, $b'(r)$. This is light backscattered from an atmospheric volume a distance r from the lidar multiplied by the intervening two way transmission. The GLAS cloud/aerosol detection and discrimination is based upon historically observed differences between cloud and aerosol layers in the magnitude of $b'(r)$, and the magnitude

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